SAND-77-0290C

CONF-770623--1

Proposed Paper
1977 Frequency Control Symposium

Th-12
28/1/77

THE FORCE-FREQUENCY EFFECT IN DOUBLY ROTATED QUARTZ RESONATORS

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Summary

Precision frequency control requirements for digital communication and position location systems currently undergoing development make it imperative that crystal resonator performance be improved in a number of aspects. Accordingly, the potential of doubly rotated quartz cuts has begun to be explored (EerNisse, 1975, 1976; Ballato and Iafrate, 1976). For cuts on the upper zero temperature coefficient locus in general ($\theta \simeq +34^{\circ}$), and in the neighborhood of the SC-cut in particular ($\varphi \simeq 21.9^{\circ}$, $\theta \simeq +33.9^{\circ}$), a variety of effects having their bases in nonlinear elasticity have been shown, or are predicted, to be reduced below the corresponding AT-cut values. In addition, the static frequency-temperature behavior shows some improvement.

Among the nonlinear effects of interest are:

A. Force-frequency

B. Acceleration (vibration) - frequency

C. Resonance amplitude - frequency

D. Intermodulation

E. Mode coupling - activity dips

F. Dynamic Thermal - frequency

G. Film stress - frequency

Some of these have received, or are receiving, theoretical and/or experimental treatments; this paper is concerned with the force-frequency effect which has thus far not been investigated in any detail for doubly rotated quartz plate vibrators. This effect relates the initial stress produced by the mounting supports to resonance frequency changes; it contributes to long-term aging and is also related to the frequency excursions produced by accelerations encountered in shock and vibration environments.

In-plane diametric forces applied to the periphery of vibrating plates produce frequency changes (order 10^{-7} per gram) that depend upon the azimuth angle ψ in the plane of the plate. If ψ is measured from the X_1'' axis, then it is found experimentally (Gerber and Miles, 1961) that for the AT-cut the effect is zero at ψ values of 60° and 120°. For the IT-cut at $\varphi = 19.1^\circ$, Ballato (1960) found the zeros to occur at $\psi = 78^\circ$ and 143° with a maximum value only one-third that of the AT-cut. This points to a reduced coefficient at the SC-cut as well.

In this paper we extend the force-frequency effect measurements to doubly rotated quartz plates on the upper zero temperature coefficient locus, concentrating on the SC- and FC-cuts because of their technological significance. The force coefficient is determined, as function of ψ, for all three thickness modes. Also given are charts of the mode spectra in the region of the thickness modes, and the modal temperature coefficients.

The force coefficient data for all three modes are compared with theoretically predicted values obtained from a variational principle applied to an anisotropic disc supported at two diametric points. This analysis departs from previous treatments (Lee et al., 1973; Lee and Haines, 1974; Lee et al., 1975) in two major respects: 1) the isotropic stress pattern is replaced by the more accurate anisotropic stress; 2) the elastic problem is treated for the general triclinic symmetry, rather than the monoclinic symmetry appropriate to rotated-Y-cuts.

These investigations verify the predicted superiority of doubly rotated quartz plates, over the conventional AT-cut, with respect to the force-frequency effect, and provide further motivation for their continued development and utilization.

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